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Strategy for testing conformance to geometric dimensioning & tolerancing standards

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Abstract

Geometric Dimensioning and Tolerancing (GD&T) information is created as part of the design process. Today, that process is performed using computer-aided design systems, which generate 3D digital product models. GD&T information is created and stored as an integral part of those models. In many industries, the goal is to reuse GD&T to drive downstream activities including engineering, analysis, production, and inspection. To achieve this goal, the software applications associated with those activities must be able to exchange and interpret GD&T information correctly and, to the extent possible, automatically. To facilitate that exchange and interpretation, ASME and ISO developed information standards for defining, representing, and presenting GD&T information. The complexity of those standards, however, frequently causes both exchange and interpretation errors. Those errors can result in significant delays and cost overruns. This paper presents a strategy for testing conformance to ISO and ASME GD&T standards. That strategy includes a testing architecture, testing requirements, test cases, and coverage analysis.

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1. Introduction

3D product models are replacing traditional 2D drawings as the primary product definition or product master [1,3,6]. Model-based engineering (MBE) uses 3D models supplemented with annotations and attributes to define product geometry and product specifications. Collectively, this information is known as Product and Manufacturing Information (PMI) [2]. PMI includes Geometric Dimensioning and Tolerancing (GD&T), 3D annotations, surface texture specifications, finish requirements, process notes, material specifications, welding symbols, and other information. PMI has the potential to allow software developers to automate various design and manufacturing functions because the software associated with these functions can process the PMI directly – a capability not supported with 2D drawings. This can save significant time and reduce costs by eliminating data re-entry delays, errors, and redundant storage [4,5].

This paper focuses on the GD&T portion of PMI. GD&T is a symbolic language for communicating permissible deviations of manufactured parts from a precise part model. All manufactured parts deviate from the precise part model at some level, since it is impossible to manufacture a "perfect" part. Designers determine what deviations in form, size, orientation, and location are permissible based on the intended use of the part. They must specify these deviations using standards for defining, representing, and presenting GD&T. Two such standards exist: ASME Y14.41-2003 [7] and ISO 16792:2006 [8]. The complexity of those standards, however, frequently causes exchange and interpretation errors. These errors can result in scrapped parts, significant delays, and cost overruns. This paper presents a strategy for testing conformance to ISO and ASME

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GD&T standards. That strategy includes a testing architecture, testing requirements, test cases, and coverage analysis.

1.1. GD&T Standards

ASME Y14.41-2003 and ISO 16792:2006 focus on presentation of engineering data in axonometric views in 3D space. These standards set rules for and provide examples of presentations of geometry and GD&T. The standards also set rules for logical association of linked data elements. The ultimate goal, though not yet achieved, is to represent those elements in a computer processible form and to drive a wide range of engineering operations. This requires data modeling and data exchange standards for presenting and representing product geometry and GD&T data (1) in native data formats, (2) in neutral data exchange formats, and (3) in visualization formats.

Presentation data is data displayed visually for human consumption. Its layout and format are extremely important. Changing either can change the meaning of the data. Representation data communicates meaning by using semantic models data associativity. Semantic models capture and represent the underlying meaning in mathematically accurate terms. These models are independent of presentation and are normally not meant for human consumption.

ASME recently expanded and enhanced its GD&T language with the release of the ASME Y14.5-2009 standard. ISO Geometrical Product Specification standards have also evolved, and significant advances are on the horizon in ISO GD&T standards. New releases of ASME and ISO standards take into account advances in Computer Aided Design (CAD), Coordinate Measuring Machine (CMM), and Numerical Control (NC) applications as well as model-based engineering processes. Nevertheless, GD&T standards still rely very heavily on presentation to explain the meaning of the data. Fully semantic GD&T representation models are still under development.

Software applications for authoring and visualizing engineering models range in capabilities, completeness, and accuracy. No formal methods or tools for testing these engineering applications for conformance to ASME or ISO standards have been published. We address this issue in the remainder of this paper. Specifically, we attempt to answer three important questions (1) why is measuring conformance important; (2) what does it mean to assert that a software application conforms to a standard or specification; and (3) how do we measure conformance to these standards?

2. Conformance testing

ISO/IEC Guide 2 defines conformance as the successful implementation of specified requirements associated with a product, process, or service [9]. Conformance testing is a method for measuring and verifying successful implementation of a standard, usually by a software application. Conformance testing has several benefits for the standard, for developers, and for users. It can expose errors in the standard and it can identify ambiguities that might cause a divergence of interpretation by implementers. Standards committees can use these issues to change the standard. For software developers, using conformance testing early can avoid costly errors late in the software development process. Conformance testing reduces the risks for users who now can use measurement tools to verify that software applications will behave as expected.

2.1. Conformance test case development

Conformance testing is a process for detecting errors. Test cases are the foundation of that process. Conceptually, a test case contains a set of inputs and prescribed outputs. The exact nature of test cases depends on the standard being tested. However, most test-case developers follow the same basic process. They begin by defining a set of test assertions (test requirements). They then analyze the standard specification for individual test assertions, write a test purpose for each assertion, and create a test case that executes each test purpose. Each assertion should be as simple as possible and focus on a fundamental “atomic” functionality. Each test should be traceable back to the specification. It must also define the expected behavior – i.e., the outputs of a conforming implementation.

If a software application passes all tests, it is said to be conformant to the standard. For a reasonably complex standard, it is rarely possible to find a complete set of test cases that definitively prove conformance. Even if such a set existed, this type of exhaustive testing would be costly and prohibitively time consuming [10]. As a result, the chosen set of test cases usually includes only a subset of all possible tests. It is important, therefore, for test developers to determine how many and what kind of test cases are required to demonstrate conformance to some level of confidence.

2.2. Conformance test coverage

Conformance test coverage is one of the most crucial concepts in conformance test development [11]. Most conformance tests use a falsification testing strategy to provide a reasonable level of confidence that an implementation conforms. Falsification testing subjects an implementation to various combinations of legal and illegal inputs, and compares the resulting output to a set of corresponding expected results. If an implementation fails even a single test – it is said to be non-conformant. The converse is not true – the absence of errors does not necessarily imply conformance. Falsification testing can only demonstrate non-conformance. Nevertheless, the larger and more complex the set of inputs is, the higher confidence we can have in an implementation that passes the conformance test. The objective is to produce tests for as many of the specification's requirements as feasible and use these tests to identify errors in implementations.

Standards developers do not often document requirements with application and test case developers in mind. Test developers must break down the specification and re-write requirements into simpler, more fundamental (formalized) requirement statements. Each requirement statement is broken down until it cannot be reduced further (hence, the term "atomic" test case). The focus of each test case is a formalized, testable conclusion derived from a specific requirement. To enable test case generation with measurable test case coverage, informal requirements are expressed as formal requirements using an appropriate specification language [12]. Formal requirements can be considered as a unique implementation of the specification. Several standards use formal requirements as a means of direct software implementation. Formal requirements are used to define coverage metrics and guide the test data generation.

3. Conformance testing for GD&T standards

Manufacturing engineering software applications are a recognized contributor to uncertainty of measured characteristics [13]. Testing and verification of engineering software is a huge and difficult task. No single and uniform set of requirements is currently available to test software applications against ISO 1101, ISO TC213 – Dimensional and geometrical product specifications, or ASME Y14.5 [14].

Researchers at The National Institute of Standards and Technology have teamed with industry researchers to develop a conformance testing capability for GD&T standards. The research team developed the software tools and test cases necessary to measure GD&T data quality and derivative model equivalence. Derivative models are those models that are translated or extracted from the native or "master" model. Derivative models include translations to alternate model native formats, open formats such as STEP, and a number of commercially available visualization formats such as 3D PDF [15].

The authors have developed test requirements, test cases, and test processes to measure a software implementation's conformance to 3D GD&T standards for representation and presentation. Our initial test case development is based on the ASME Y14.41-2003 standard and the underlying PMI-defining standards, including ASME Y14.5-2009 and ASME Y14.6-2001. The ASME Y14.41 standard addresses three distinct application areas: model only, model and drawing, and drawing only [16].

3.1. Test requirements and test case development

ASME Y14.41-2003 contains requirements for the preparation and revision of digital product definition data. Many of these requirements pertain only to simplified 2D drawings supplemented by 3D models. The rest can be divided into two categories: design activity requirements, and model/viewer application requirements. Design activity requirements pertain to the product definition data set. ASME Y14.41 defines a product definition data set as "digital product definition data." These requirements address the content and structure of the data set. Model/viewer application requirements pertain to the capabilities of the modeling or viewing tools. We will focus on the latter requirements to determine modeler/viewer software application conformance. Based on these requirements, we propose five GD&T concept categories and associated test cases: directly toleranced dimensions and dimension symbols, basic and reference dimensions, geometric tolerances, datum features and datum targets, and dimensioning and tolerancing constructs.

We have developed a large number of test cases for each of these categories. Each of these test cases will be implemented in native format for several different computer aided design systems and in the STEP neutral format. Once validated, these test cases can serve as reference models for application developers. Fig. 1 shows example "atomic" test cases. Each atomic test case addresses only a single test requirement.

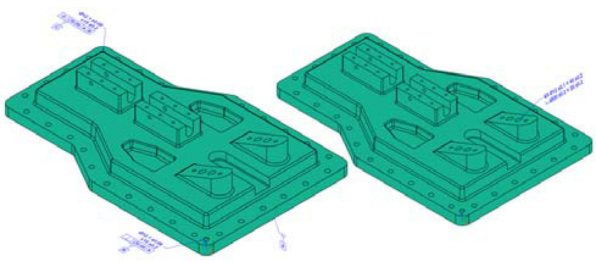

Fig. 1. Example "atomic" test cases. Each test case is limited to one PMI requirement.

3.2. Conformance test process

For a conformance test to be meaningful, it must correctly implement the standard specifications, provide adequate coverage of the standard, be consistent for all implementations, be repeatable, and be executable in a reasonable amount of time. A test method is a defined technical process for performing a test. A test is the technical operation that consists of the determination of one or more characteristics of an implementation.

Our proposed conformance test process consists of three steps. Step one determines if each of the test cases can be constructed correctly in the system under test (SUT). Step two saves the test case in the SUT's native format and then reads it back to verify that the presentation is consistent. These steps are shown in Fig. 2. Step three exports each test case to a neutral format and checks the representation of each test case.

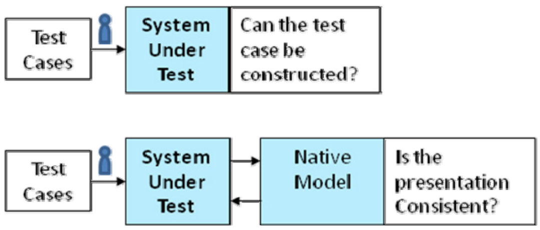

Fig. 2. Test case construction and round trip test

The checking is done by comparing derivative model in neutral format to a validated neutral model instance derived from each test case as shown in Fig. 3. An alternate procedure would be to use the application-programming interface (API) to interrogate the internal representation of the test case and compare it to expected results.

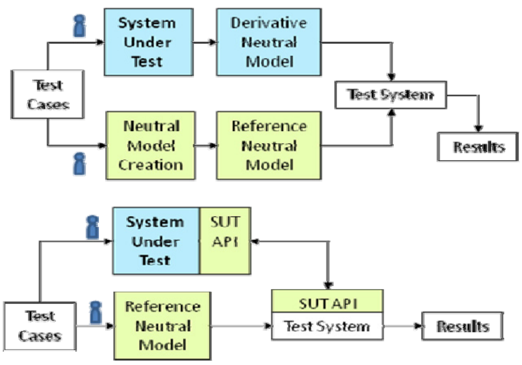

Fig. 3. Representation test using neutral model or application programming interface (API)

Fig. 4 shows our proposed automated process for testing GD&T representation. In this process, an input test case is read from a neutral model format and then written to an output model in neutral format. This neutral model is then compared to the expected result. If the model produced by the application matches the input test case, one can infer the internal representation in the application conforms to the standard. One disadvantage of writing out a neutral model format for comparison to the test reference is the application is not completely isolated since the output translator itself could generate errors.

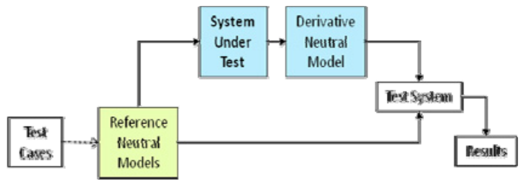

Fig. 4. Automated representation test using a neutral format eliminates manual entry to facilitate batch processing

4. Summary

Manufacturing enterprises are using model-based engineering techniques with increasing success, but technical barriers remain. MBE relies on 3D digital product models, not on 2D drawings. Product Manufacturing Information including GD&T is created and stored as an integral part of those models. In many industries, the goal is to reuse PMI to drive engineering activities including simulation, analysis, production, and inspection. To achieve this goal, the software applications associated with those activities must be able to exchange and interpret G&T information correctly – based on existing ASME and ISO standards. The software applications, however, insert a layer of interpretation between the user and the model data. The fundamental question is – does that interpretation conform to those standards. New releases of ASME and ISO standards for GD&T take into account MBE requirements. Those releases also recognize that the application of geometric tolerancing to solid models still relies very heavily on presentation data to explain the meaning of the specifications. The potential is great for the same GD&T data to be interpreted and presented differently by different engineering and manufacturing applications. Misinterpretation and incorrect presentation of GD&T can result in significant delays and costly errors. No single and uniform set of requirements is currently available to test software application conformance to GD&T standards. This paper describes a strategy for testing engineering software applications for conformance to ISO and ASME standards for GD&T presentation. It includes an overall architecture, conformance requirements, and test case development.

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